DIVISION OF CONSTRUCTION AND RESEARCH

TRANSPORTATION LABORATORY

RESEARCH REPORT

EMBANKMENT CONSTRUCTION UTILIZING SANITARY LANDFILL MATERIAL

FINAL REPORT

CA-DOT-TL-2164-1-75-35

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California's first major highway embankments incorporating waste materials from a sanitary landfill have been constructed. Approximately 200,000 cubic yards of waste were mixed with soils and placed in layers within several embankments near Irvine, California. No change in, or deviation from, the special provisions of the project contract was required. The results obtained benefited both the State of California and the Contractor. Savings to the State are estimated at $900,000.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION AND RESEARCH
TRANSPORTATION LABORATORY

December 1975

TL No. 652164

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

EMBANKMENT CONSTRUCTION UTILIZING
SANITARY LANDFILL MATERIAL

Study made by	Geotechnical Branch
Under the Supervision of	Raymond A. Forsyth
Principal Investigator	R. H. Prysock
Report Prepared by	J. P. Egan, Jr. L. R. Leech J. Campbell

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

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The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification or regulation.

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INTRODUCTION

California's first major highway embankments incorporating sanitary landfill refuse as fill material on a large scale were recently completed on State Route 73 in Orange County. The employment of soil and refuse mixtures within embankments marked a significant milestone in the history of the California Highway System. In the past, engineering practice generally precluded placement of material other than soil and rock within earthwork structures. Refuse, except for deep-seated tree stumps, was regarded as detrimental to structural integrity and avoided, or removed, often at considerable expense. Although the project herein described was of an experimental nature, prompted by a significant economic factor, its success may well lead to use of waste products in future highway construction when conditions are favorable.

This report describes the use of refuse combined with soil and presents an outline of design specifications, construction techniques, and control test methods employed.

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CONCLUSIONS AND RECOMMENDATIONS

For decades refuse has been hauled from urban centers to outlying districts for interment in sanitary landfills. However, as these urban centers expand, the "outlying" areas are frequently enveloped by growth and once again the refuse presents a problem. As many of the dump sites encompass broad areas, it is inevitable that developing transportation corridors will have to traverse them from time to time. The Route 73 project solution to such a problem may well serve as a model for future earthwork projects where the situation and circumstances are similar.

Listed below are several conclusions resulting from this study together with recommendations that may prove of value in future projects.

1. The use of sanitary landfill refuse in roadway embankment construction proved very successful for the subject project from both economic and construction view points. The lamination concept worked well to produce stable embankments. The embankment design effectively sealed potential contaminants within the structure, preventing pollution of the external environment.

The economic success of the project was due in large measure to imaginative and vigorous prosecution of various phases of the work by the contractor. Undeterred by early problems, he developed efficient methods for excavating, hauling, and mixing refuse. Careful scheduling of the multi-stage embankments and cycling of operations in areas overwetted by saturated refuse minimized delays and down time.

2. The sandy, cohesionless type soil available on the project for blending with the refuse proved to be a definite asset. Fine-grained clays and silts, critical to moisture content and difficult

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to compact at best, might well have resisted blending with refuse, creating voids in the mass and resultant low densities.

3. The composition of a sanitary landfill may be such that blending with soil is not always required. For example, a portion of the landfill on this project contained sufficient quantities of soil so that further blending was often judged unnecessary. Alert visual observation of all incoming material by grading inspectors is indispensable to quality control in an operation of this type.

4. The state and composition of any sanitary landfill being considered for use as embankment material or in-place foundation material should be determined during the subsurface exploration phase of the project. The conventional small boreholes are not considered satisfactory for this purpose. Trenches would provide a more representative sampling and large diameter bucket auger holes spotted throughout the area could provide supplemental data.

5. Utilization of refuse within embankments must be preceded by a careful evaluation of any potential effects upon the environment. A principal consideration is the proximity to groundwater at the site and the historical fluctuations of the groundwater tables. Permeability values for foundation soils and other soils that may be used as fill material must be considered in the refuse embankment design. Appropriate measures must be taken to prevent proliferation of obnoxious odors emanating from excavated refuse. A potential for spontaneous combustion of refuse components is incurred when a sanitary landfill is reopened to the air. Provision should be made to forestall such an eventuality.

6. It is recommended that serious consideration be given on future projects traversing sanitary landfills to constructing the roadway over the landfill deposits. Treatments of the in-situ material necessary to insure stability and minimize post-construction settlement would be determined after careful inspection and evaluation of the landfill contents as outlined above.

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DEFINITIONS

Differences between sanitary landfill and an engineered fill comprised of rubbish and soil are outlined below:

Sanitary Landfill - Sanitary landfill is placed by dumping refuse in layers, or lifts, some 5 to 15 feet in thickness, usually within excavated pits or natural depressed areas. The waste is generally compacted to some extent using mechanical equipment such as bulldozers or front-end loaders. The volume of the refuse can be thereby reduced to one-half or even one-fourth of its delivered volume, in effect increasing its density to about 30 to 60 pounds per cubic foot. The waste is then covered with soil to minimize odor, rat infestation, and insect nuisance. Generally, a 6 inch earth cover is placed on each segment of the fill at the close of each day. A sanitary landfill, therefore, consists of wastes in large cells or blocks, compartmentalized or encapsulated within thin membranes of soil. These cells may be compartmentalized in thin strata over large broad areas; in relatively long deep trenches; or in wedges on slopes. A final cover of soil one or two feet in depth is placed over the landfill to level the surface and present a neat appearance (1).

Engineered Fill - The engineered fill utilizing refuse, as is the case with all earth work structures, must be constructed to specified standards with regard to compaction and density to provide support for anticipated loads and to ensure stability of the mass. Additional considerations with regard to the engineered fill are differential settlement, punching shear, rotational shear, and corrosion of any structural members within the fill composed of concrete, steel, etc., such as culverts or other conduits.

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BACKGROUND INFORMATION

Project Description

The embankments described in this report form part of the first stage construction of a portion of Route 73 extending between Bonita Canyon Road and Jamboree Road, adjacent to the cities of Irvine and Newport Beach, in Orange County. The 1.5 mile project involves the realignment of Veterans Memorial Highway (MacArthur Boulevard) and construction of embankments for a future Route 73 freeway. The principal feature of the project is the University Avenue Interchange complex. The project design required relocation of several heavily travelled arterials as well as access roads into Irvine Campus of the University of California, which lies immediately east of the project limits. The project design was further complicated by San Diego Creek; a leveed waterway which crosses the alignment on an east-west axis. The project layout and its surrounding areas are depicted in Figure 1.

Site Description

The project traverses the north-western tip of the San Joaquin Hills. Geologic formations encountered in these hills consist of poorly consolidated terrace deposits overlying Miocene strata of interbedded shales and generally soft sandstone(2). The San Diego Creek Channel is underlain by beds of highly compressible clays. The project area is drained by San Diego Creek, a major water course of Orange County, and Bonita Canyon Creek to the south, which feeds into San Diego Creek. The area has been subjected in recent years to periodic flooding. San Diego Creek is considered to be the fringe of the Tustin Plain Area of the Orange County Coastal Plain groundwater basin. South of the creek are encountered the essentially non-waterbearing San Joaquin Hills.

Borings shown on Figure 2 disclosed groundwater 2.0 feet above sea level during the foundation investigations of November and December 1970.

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FOUNDATION INVESTIGATION

In 1969 a foundation exploration at the project site was conducted by the District 07 Materials Department. Samples removed from two 55 foot deep borings and logs of four earlier bucket rig borings were submitted to the Transportation Laboratory in Sacramento for evaluation, and recommendations were requested for the construction of proposed 35-foot high embankments. Locations of the borings are shown on Figure 2.

From the various borings a generalized profile of the foundation soils was established. Extending from the surface down, the profile consists of a moist, brown, silty fine to medium sand to a depth of seven feet. Overlying this stratum, of course, is the four to five foot embankment and structural section of existing MacArthur Boulevard through which the borings were made. The sand overlies a two foot layer of soft, dark gray silty clay that rests upon a nine foot layer of wet, loose, blue-gray silty fine to coarse sand. Underlying the sand is a five-foot stratum of firm blue-gray silty clay with a small amount of organic material and some sea shells. The clay overlies a three-foot layer of loose, blue coarse sand that is underlain by a two-foot layer of firm, blue clay. A six foot layer of gray, coarse sand with gravel is then underlain by a 15-foot stratum of firm to stiff blue-gray silty clay containing some shells and organic material. This stratum rests on a firm, gray, silty fine to medium sand in which both borings were bottomed. The general pattern of foundation soils, therefore, consists of alternating strata of compressible clay and fine to coarse sands that appear to be free draining.

In its report dated January 9, 1970, the Laboratory concluded that the weak foundations could support the desired fill heights provided that certain design and construction provisions were specified(3). Among these were controlled loading rates, stabilizing berms and field instrumentation as a means of construction control.

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DESIGN CONSIDERATIONS

In view of the low strength of the foundation soils the following embankment construction requirements were included in the special provisions to the contract:

1. Strip surface materials of refuse embankment sites to Elevation 4.0.

2. Construct embankments to finished embankment height subject to the following rates of loading:

   a. Initial 9 feet of embankment to be placed at a rate of 1.33 feet per week, followed by a waiting period of 90 days.

   b. Second stage: Construct the embankments to Elevation 22.0 at a rate not to exceed 1.33 feet in any seven consecutive calendar days, followed by a 60 day waiting period.

   c. Third stage: From 18 feet of embankment height (Elevation 22.0) to finished grade elevation, construction should be at a uniform rate not to exceed three feet in any seven consecutive calendar days.

The roadway design that evolved subsequent to the foundation study was oriented to a geometric configuration of wide expanse with contiguous embankments and 2:1 side slopes. The proximity of the Unviersity Campus rendered aesthetics an important consideration; therefore, some additional filling and terracing were specified to complement the visual effect.

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The realignments of MacArthur Boulevard and University Drive North presented a special problem to construction inasmuch as they traversed an abandoned sanitary landfill.

Since construction of the roadway embankments over the "in-place" sanitary landfill would subject them to long term subsidence and differential settlements of intolerable magnitude, removal of the contents was deemed essential and so specified in the Materials Report for the project.

The sanitary landfill had been placed by Orange County during the period November 1954 to March 1961. A portion of San Diego Creek was rechannelized to provide adequate space for the dump. Upon completion, the landfill had been covered with a two foot blanket of soil seeded to grass. The total surface area of the landfill encompassed 145 acres and some 200,000 cubic yards of refuse lay within that portion to be traversed by roadways. The dump material consisted of wood, stumps, paper, fibrous wastes, rags, cans, bed springs, pipes, wire, glass, plastics, tires, brick, concrete, earth, stone, and water. At the time of excavation degradation of these materials was found to have been minimal during the intervening 13 years, i.e., newspapers dated 1959 were in "garage-stored" condition and completely legible.

During the planning and design phase of the Route 73 project it was apparent that disposal outside the job limits of the contents of the sanitary landfill and importation of substitute materials to offset the loss in volume would entail a very large expenditure. An economic analysis established that it would be much less expensive to dispose of the refuse within the project embankments. The results of the analysis indicated that costs of removing the refuse from the job limits would be at least twice that of utilizing it in the embankments. Another important factor influenced the decision

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to use the refuse on the project. Hauling 200,000 cubic yards of trash in heavy equipment over public thoroughfares to the nearest available site (3 miles distant) would incur serious traffic problems over an extended period of time. However, when the special provisions for the project were drawn up, the option to use the refuse in fill construction or to dispose of it at a site off the job limits was left to the contractor. The contractor elected to utilize it. The 200,000 cubic yards of refuse were excavated at a cost of $2.00 per cu yd and placed within the embankments at a cost of 30 cents per cu yd (1974-75 costs). By so doing, an estimated total saving of approximately $900,000 was achieved.

Refuse Embankment Design and Controls

The Department of Transportation had been aware for sometime that refuse materials could be employed within embankment-supporting foundations. New York State's experience in constructing highways over in-place sanitary landfill as early as 1952 is part of the literature(4). Utilization of refuse material within embankments, however, lacked precedent. The project designers were therefore required to formulate a method for erecting a sound structure together with appropriate quality controls during construction.

The procedures eventually evolved by the Department employed a lamination concept comprised basically of alternating layers of soil-refuse mixtures and soil alone. It was specified that refuse be spread over the grade and then mixed with soil in equal part, by volume. Refuse constituted of solids such as rock, concrete, and metals would not exceed one foot in the vertical dimension when placed in embankments. Other materials, including biodegradable waste, were limited to 1/2 foot in greatest dimension. Each mixture layer would be overlain by two individually compacted layers of soil. Moisture content at compaction was to approximate optimum

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as determined for the soil fractions. Compaction of the mass was specified as 90% of maximum density as determined for the soil by Test Method No. Calif. 216. In-place densities would be monitored by nuclear gage determinations together with visual inspection. It was stipulated that refuse material would not be permitted within 4 feet of embankment finished grade. The specifications for construction of the Route 73 embankments are listed in the attached Appendix.

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CONSTRUCTION METHODS AND EQUIPMENT

Refuse Excavation

The nature of the sanitary landfill material coupled with the contractor's inexperience in handling it combined to create some field problems early in the work. The contractor had to adapt equipment and techniques to the new media on a trial and error basis.

Initial attempts to excavate the wastes utilizing front end loaders proved unsuccessful. When large masses of saturated materials such as paper and rags were encountered the bucket was not easily filled. Excess contaminated water ponded, immobilizing the equipment. The loader could not efficiently transfer excess water to a collection point for removal.

The device that proved most successful for excavating and loading refuse into trailer rigs was the hydraulic backhoe. This machine had several advantages. Digging action from the top downward into the saturated refuse penetrated on the initial thrust and filled the bucket. Wet, soft areas were worked by reaching out and down, with the machine carriage resting on firm ground. The backhoe effectively controlled contaminated water pending disposal. Refuse was deposited into the trailers with the backhoe as it was excavated at a rate of about 300 cu yds per hour.

Groundwater encountered within the sanitary landfill excavations was isolated, pumped into tank trucks, and hauled to the embankments for use as mixing water. No discharge of this contaminated fluid was permitted into San Diego Creek. A typical cross-section showing the excavation limits of the sanitary landfill and the roadway prism constructed in its place is shown in Figure 4.

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Fill Placement

Refuse material was hauled to the embankment areas with rear dump trailer and tractor rigs of the type shown in Figures 11 and 12. Bulldozers spread the material into layers approximately 1/2 foot thick as depicted in Figures 7, 8, and 9. At this point those components deemed unsuitable, such as tires, were selectively removed by hand labor; stockpiled, and hauled away for disposal at a public dump as illustrated in Figures 15, 17, 18 and 19.

Sandy soils were hauled to the site in twin bottom dump trailers and spread over the in-place refuse with rubber tired dozers and a motor grader (Figure 16).

After the soil was placed over the rubbish layer, mixing was accomplished with a self-propelled sheepsfoot compactor (shown in Figure 13) and sheepsfoot type compactors pulled by bulldozers. The compactor spikes penetrated the soil and rubbish, pulling, ripping, and splitting the rubbish while it was being mixed with the soil and compacted.

Some difficulty was experienced during mixing operations in preventing compactor spikes from plugging with refuse. Fortunately, the sandy, relatively cohesionless soils facilitated the blending operation. It is conjectured that fine-grained clay soils would be extremely ill-suited to blending with refuse. Control of the blended refuse layers was achieved by visual inspection. Inspectors observed blending and compaction of the materials and directed modifications of the operation when necessary. Excavation for a drainage culvert through a portion of a partially completed embankment exposed to view layers of the blended refuse, as seen in Figure 20. The blended refuse layer can be seen across the center of the photograph, sandwiched between soil layers. Closer views of the blended layer (Figures 21 and 22) indicate

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the compact state of the mass and the absence of voids. The soil and refuse was in a moist state, well mixed, and considerable force was required to separate refuse components from the soil matrix.

The moisture content of excavated refuse when delivered to the grade varied from dry to saturated.

During construction of the embankments it was frequently necessary to move grading operations to alternative locations to permit over-wet areas to dry to an optimum moisture.

Leachate was not considered to be a problem and no program to monitor leachates from the embankments was initiated since the refuse was incorporated in embankments several feet above the water table, sandwiched between layers of relatively impermeable soil.

Staged fill construction was utilized to avoid failure of embankments or structures due to low-strength clays in the substrata. The height and waiting period for each stage was based upon the analysis of the foundation exploration and tests performed on these materials. Stabilization berms were carefully fitted to existing ground to achieve a pleasing aesthetic appearance.

During the design phase for the project it had been surmised that the utilization of materials from the sanitary landfill would result in the release of objectionable odors. The special provisions for the contract, therefore, directed the Contractor to take suitable measures to counter such odors during excavation and spreading operations. A commercial deodorant was obtained and held available, however the problem of odors proved to be minor and treatment was not required.

A program for monitoring settlement and controlling the rate of fill construction was instituted. Heave stakes, piezometers,

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settlement platforms, elevation benchmarks, and inclinometers were used to monitor the rate, extent, and amount of settlement that occurred in the substrata. After completion of the fills, additional benchmarks were installed on the fills above the settlement platforms to monitor any compression that may occur with the fill itself. Field monitoring will continue until an acceptable stable condition is reached.

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REFERENCES

1. Sowers, George F., "Foundation Problems in Sanitary Landfills", Jnl. Sanitary Engr. Div., ASCE, Feb. 1968, pp 103-116.

2. Materials Report for the Proposed Construction of the Route 73 Freeway from Route 1 to Route 405; California Division of Highways, District 07; Oct. 1969.

3. Report of Foundation Investigation at the Proposed University Avenue Interchange; California Division of Highways, Materials and Research Department; Lab Auth. 32065, January 9, 1970.

4. Moore, Lyndon H., and McGrath, Maurice E., "Highway Construction on Refuse Landfills", Highway Focus, Vol. 2, No. 5, Dec. 1970, pp 11-26.

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APPENDIX

Excerpts from the Special Provisions, Contract No. 07-036124, 07-Ora-73, P.M. 2.7/4.0

10-1.15 EARTHWORK.--Earthwork shall conform to the provisions in Section 19, "Earthwork," of the Standard Specifications and these special provisions.

At the option of the Contractor, and to the extent that material from excavation within the project limits is available, embankment shall be constructed of borrow or of material obtained from excavation within the project limits or a combination of borrow and material obtained from excavation within the project limits. When borrow is local material, such borrow shall be obtained from sources in accordance with the provisions in Section 6-2, "Local Materials," of the Standard Specifications.

To the extent that embankments are available, excavated materials shall either be hauled to embankment areas or disposed of outside the highway right of way in accordance with Section 7-1.13, "Disposal of Material Outside the Highway Right of Way," of the Standard Specifications as the Contractor may elect, except that in no case shall the Contractor dispose of material which has been excavated from the roadway until the planned embankments have been constructed to the extent that the material remaining in excavation in the roadway is in excess of the amount necessary to complete the remaining planned embankments and at no time shall material excavated from the roadway, other than that which is unsuitable for embankment construction, be disposed of to the extent that the planned embankment remaining to be constructed is in excess of the remaining materials to be excavated from the roadway.

The Contractor, at his option, may compact the ground surface on which embankment is to be constructed before placing any embankment material thereon. If said compaction results in an average subsidence exceeding 0.25-foot, the ground surface will be measured after completion of the compaction. The Engineer shall be allowed the time nocessary to complete the measurement of an area before placement of embankment material is started in said area.

The total quantity of embankment will be computed in the same manner as specified for roadway excavation in Section 19-2.08, "Measurement," of the Standard Specifications, on the basis of the planned or authorized cross section for embankments and the measured ground surface. A quantity of 5,000 cubic yards of embankment will be added to the computed embankment quantity for the anticipated effect of any subsidence which may occur after the placing of embankment material has begun. No adjustment will be made in the event that the actual subsidence is more or less than that anticipated. No adjustment will be made in the pay quantity for consolidation that may occur in the embankments.

Quantities of embankment measured as specified herein will be paid for at the contract price per cubic yard. Such price shall include full compensation for furnishing all labor, materials (except material obtained from excavation within the project limits), tools, equipment and incidentals, and for doing all the work involved in constructing embankments, complete in place, including hauling borrow material, spreading

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Surcharge embankments shall be constructed above finished grade of the Bonita Canyon Creek Box Culvert. Surcharge embankment and final settlement periods of the surcharge embankments over the Bonita Canyon Creek Culvert shall conform to the following:

Stationing	Surcharge Height - Feet	Settlement Period - Days
46+35 - 50+00)	10	90
0+00 - 1+00	4	90

Excavation for the footings or driving the foundation piles at Abutment No. 12 of Bridge No. 55C-60 shall not be done until the expiration of the final settlement period for the embankment within 100 feet of Abutment No. 12.

The duration of the required settlement period at each location will be determined by the Engineer. The interim and final settlement periods referred to herein are estimated. The Engineer may order an increase or decrease in any estimated settlement period. Such increase or decrease in any settlement period will result in an increase or decrease in the number of working days allowed for the completion of the work if the settlement period involved is considered to be the current controlling operation as defined in Section 8-1.06, "Time of Completion," of the Standard Specifications. Neither the Contractor nor the State will be entitled to any compensation other than an adjustment of contract time due to increases or decreases in the settlement periods.

The removal of surplus embankment material, placed as a settlement or surcharge embankment, where such material is removed to conform to the finished slope lines shown on the plans, will be paid for at the contract price per cubic yard for roadway excavation.

Those areas shown on the plans as "Refuse Removal Area" are areas of unsuitable material. The Contractor shall excavate the refuse cover and refuse material and construct embankments within the excavated refuse area with material obtained from excavation within the project limits (except excavated refuse material) or borrow.

At the option of the Contractor, excavated refuse material may be used in embankment construction in the areas shown on the plans as "Refuse Embankment Areas."

In addition to the requirements in Section 19-5, "Compaction," and Section 19-6, "Embankment Construction," of the Standard Specifications, the placement of excavated refuse material in embankments shall conform to the following:

1. Excavated refuse material shall be thoroughly mixed with suitable embankment material at a rate not to exceed 50 percent of the mixture.

2. Each layer of the refuse material mixture shall be covered with at least 2 layers of suitable embankment material.

3. No layer of the refuse material mixture shall be placed within 4 feet of finished grade.

4. Rock, portland cement concrete, asphalt concrete, ferrous and non-ferrous metals shall not exceed one foot in the vertical dimension when placed in embankments.

5. All other material including biodegradable material shall not exceed one-half foot in greatest dimension.

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and compacting embankment material, and compaction and preparation of the subgrade at the grading plane in embankment areas, all as shown on the plans, as specified in the Standard Specifications and these special provisions, and as directed by the Engineer.

Roadway excavation and structure excavation, will be paid for as specified in these special provisions and in Sections 19-2, "Roadway Excavation," 19-3, "Structure Excavation and Backfill," and 19-4, "Ditch Excavation," respectively, of the Standard Specifications, except that when material is used in roadway embankment, the work of spreading after depositing, compacting and preparing subgrade at the grading plane in roadway embankments will be paid for at the contract price per cubic yard for embankment.

Full compensation for all haul will be considered as included in the contract price paid per cubic yard for the excavated material and no separate payment will be made therefor.

Surplus material used to widen slopes in accordance with the provisions in Section 19-2.06, "Surplus Material," of the Standard Specifications will not be measured or paid for as embankment.

Embankment construction shall conform to the following sequence of operations:

1. Initial Stage (0-9 feet of embankment height).--The first 9 feet of embankment height (or to finished embankment height if less than 9 feet) shall be spread over as large an area as practicable. In areas where refuse material has been removed the initial stage of embankment construction shall be to a maximum elevation of 19.00 instead of a maximum 9 feet of embankment height.

2. First Interim Settlement Period.--Following the initial stage of embankment construction, an interim settlement period of 60 calendar days will be required during which time no further material shall be placed over the initial stage of embankment construction.

3. Second Stage (9-18 feet of embankment height).--Following the first interim settlement period, the next 9 feet of embankment height (or to finished embankment height if less than 9 feet) shall proceed at a rate not to exceed 1.33 feet in height in any 7 consecutive calendar days.

4. Second Interim Settlement Period.--Following the second stage of embankment construction another interim settlement period of 60 calendar days will be required during which time no further material shall be placed over the second stage of embankment construction.

5. Third Stage (over 18 feet of embankment height).--Following the second interim settlement period, embankment construction shall proceed to finished height at a rate not to exceed 3 feet in height in any 7 consecutive calendar days.

In addition to the interim settlement periods described herein, final settlement periods are required for the bridge approach embankment at Abutment No. 12 of Bridge No. 55C-60 and along the entire length of the Bonita Canyon Creek Box Culvert. A final settlement period of 365 calendar days is required at Abutment No. 12 of Bridge No. 55C-60.

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Suitable embankment material referred to herein shall be considered as material excavated from within the limits of this project (except refuse material) or borrow.

During the operations of excavating and depositing refuse material, the Contractor shall take precautions to prevent offensive odors within the surrounding area. Such precautions may consist of the use of earth cover or the application of commercial odor masking compound as directed by the Engineer. Precautions to prevent offensive odors will be paid for as extra work as provided in Section 4-1.03 of the Standard Specifications.

Excavation of refuse material will be paid for as roadway excavation (Type A).

Excavation for the Bonita Canyon Creek Culvert and its inlet and outlet structures will be paid for as roadway excavation.

Backfill for the Bonita Canyon Creek Culvert will be paid for as structure backfill (Type C).

The limits of payment for structure backfill (Type C) are shown on the plans.

When a layer of specified material is not to be placed on the basement material, the finished grade at any point shall not vary more than 0.50-foot above or below the grade established by the Engineer. The requirements for obtaining a relative compaction of 95 percent, as provided in the first 2 paragraphs in Section 19-5.03, "Relative Compaction (95 Percent)," of the Standard Specifications, shall not apply when a layer of specified material is not to be placed on the basement material.

Where new pavement or curb is to be placed adjacent to the existing pavement, the edges of existing pavement shall be cut to a neat line which shall not vary more than 0.1-foot from a straight line.

Full compensation for cutting existing pavement to the neat line shall be considered as included in the contract price paid per cubic yard for roadway excavation and no separate payment will be made therefor.

The portion of imported borrow placed within 4 feet of finished grade shall have a Resistance (R-value) of not less than 15.

Structure excavation for footings at Pier Nos. 9 & 10 of Bridge No. 55C-60 will be paid for at the contract price per cubic yard for structure excavation (Type D). Ground or surface water is expected to be encountered at these locations.

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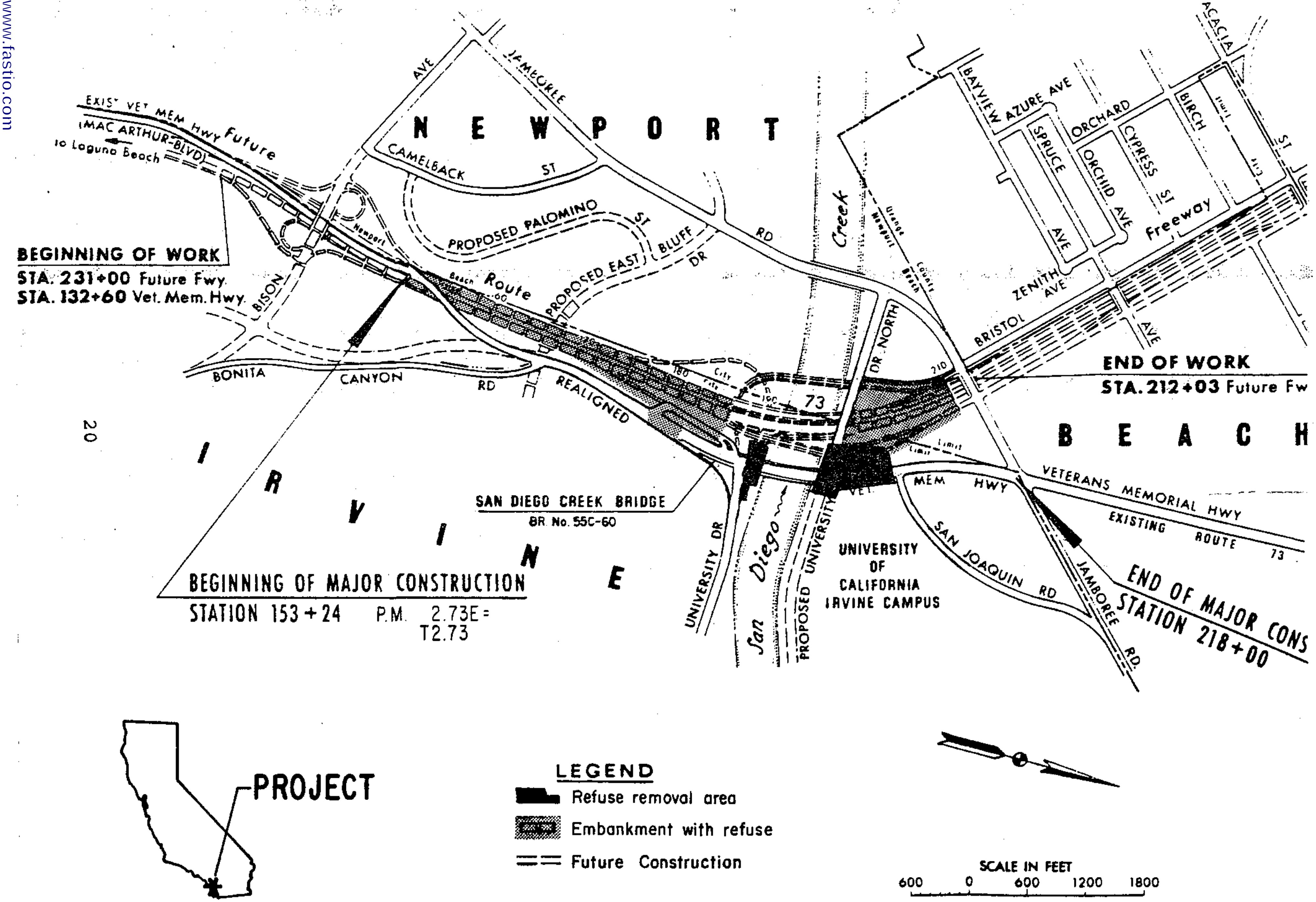

Figure 1 LOCATION MAP

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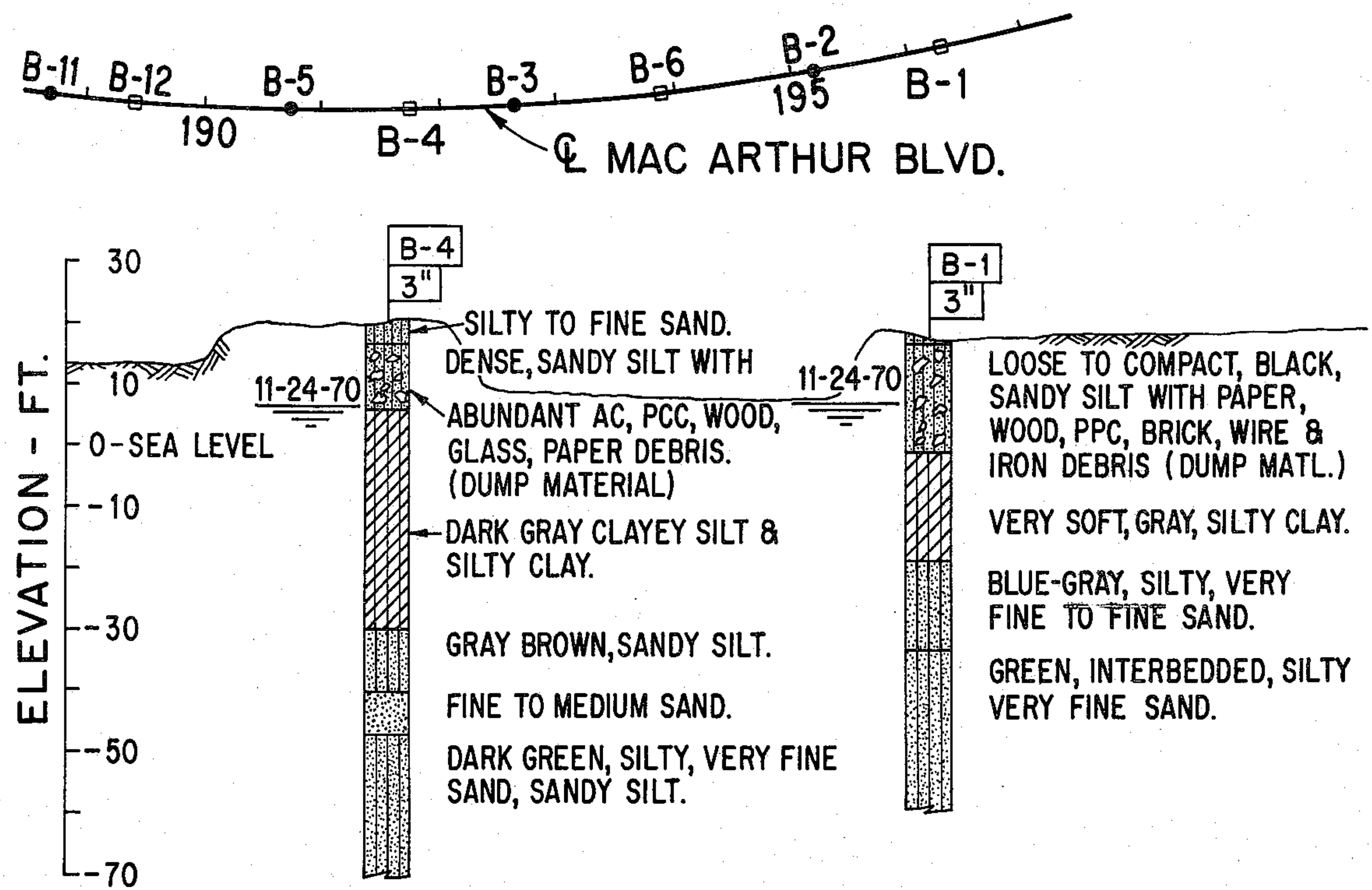

Figure 2

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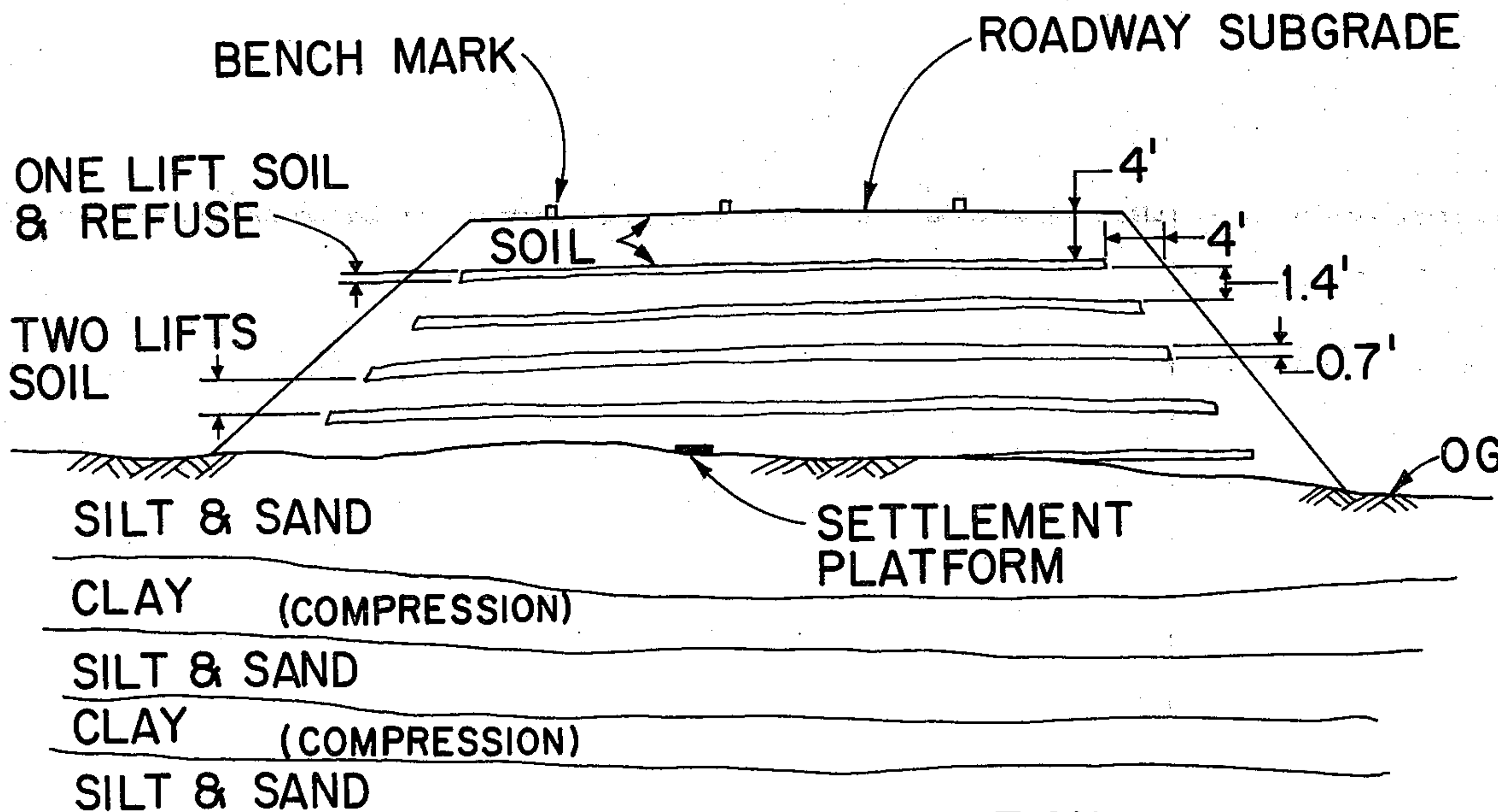

TYPICAL CROSS SECTION OF ENGINEERED REFUSE FILL AND SUBSTRATA

(NO SCALE)

Figure 3

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REFUSE REMOVAL AREA

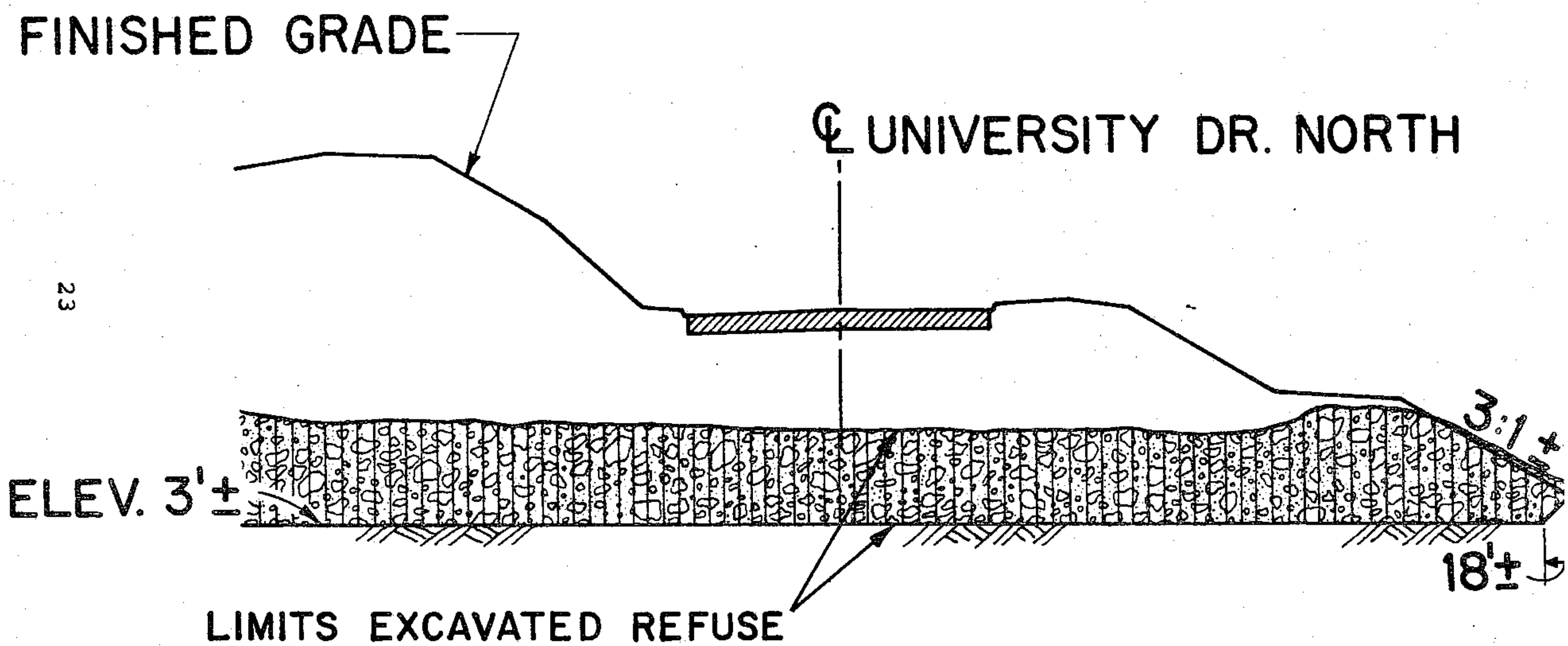

Figure 4

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Figure 5 View of sanitary landfill prior to excavation.

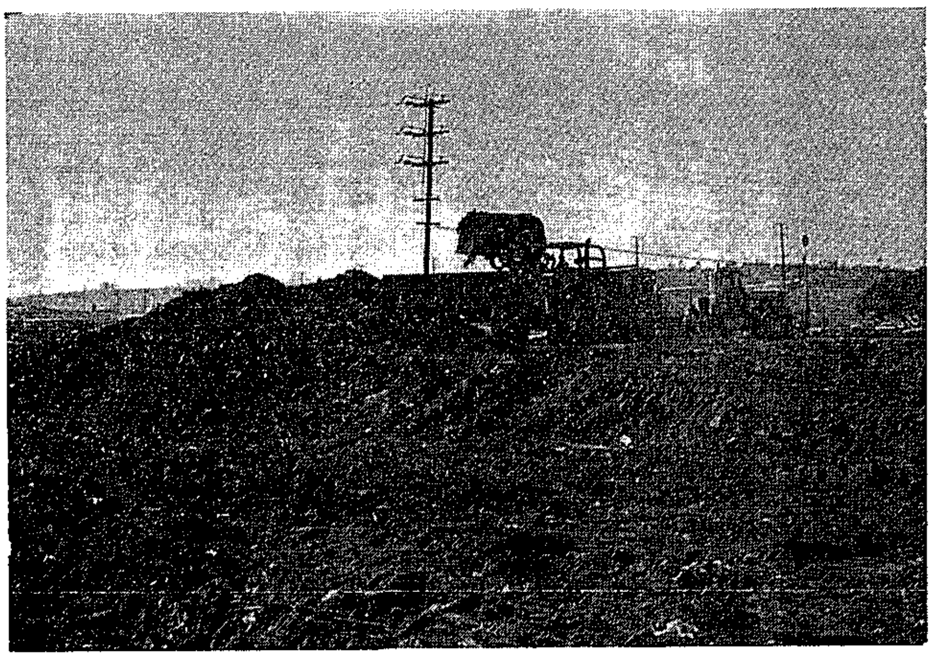

Figure 6 Front end loader in operation.

Figure 7 Refuse in place, ready for mixing with soil.

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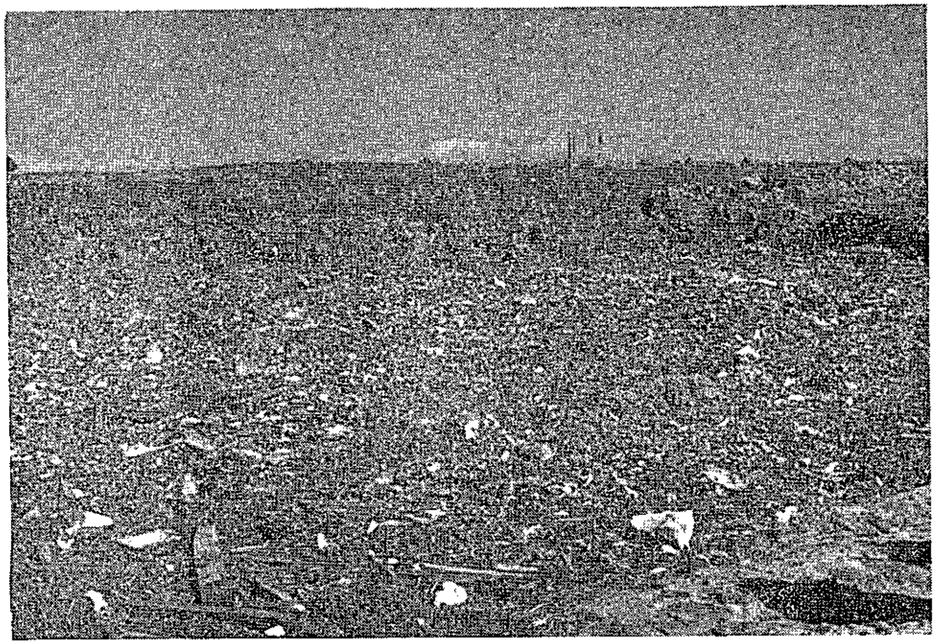

Figure 8 Refuse spread for mixing with soil.

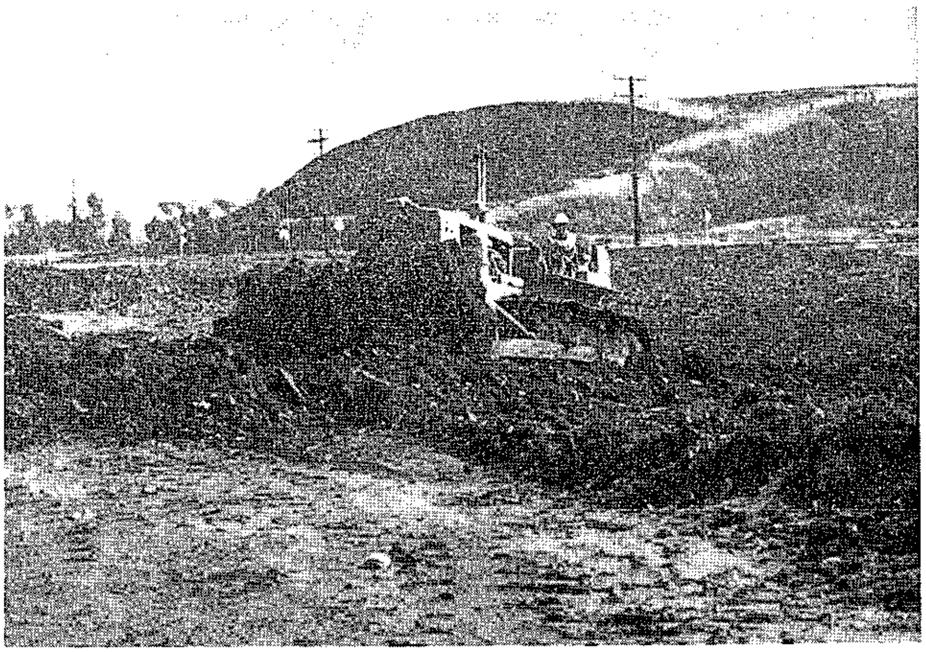

Figure 9 Spreading refuse material in ½ foot lift.

Figure 10 Tire removed as unsuitable

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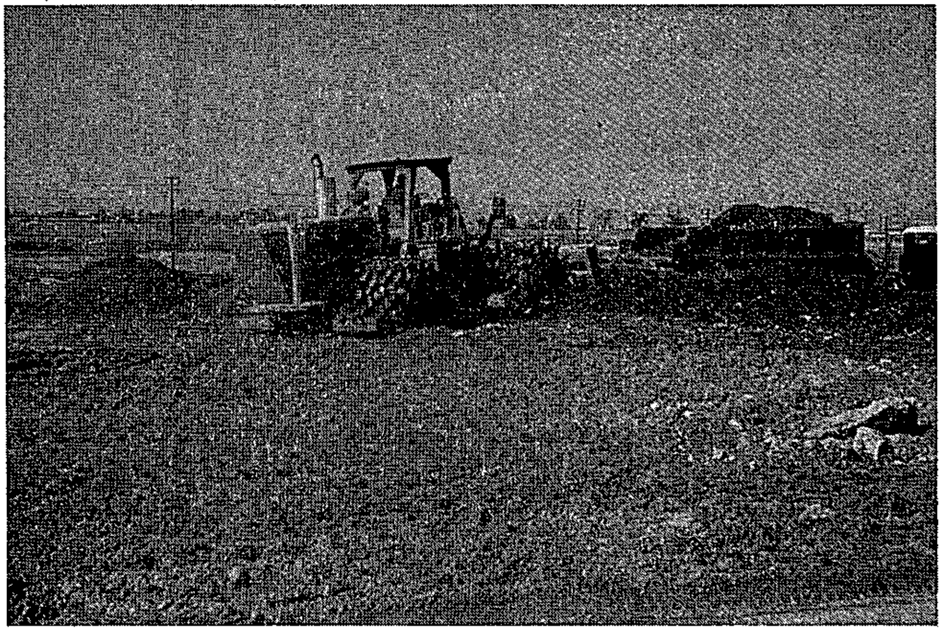

Figure 11 Sheepsfoot compactor in operation.

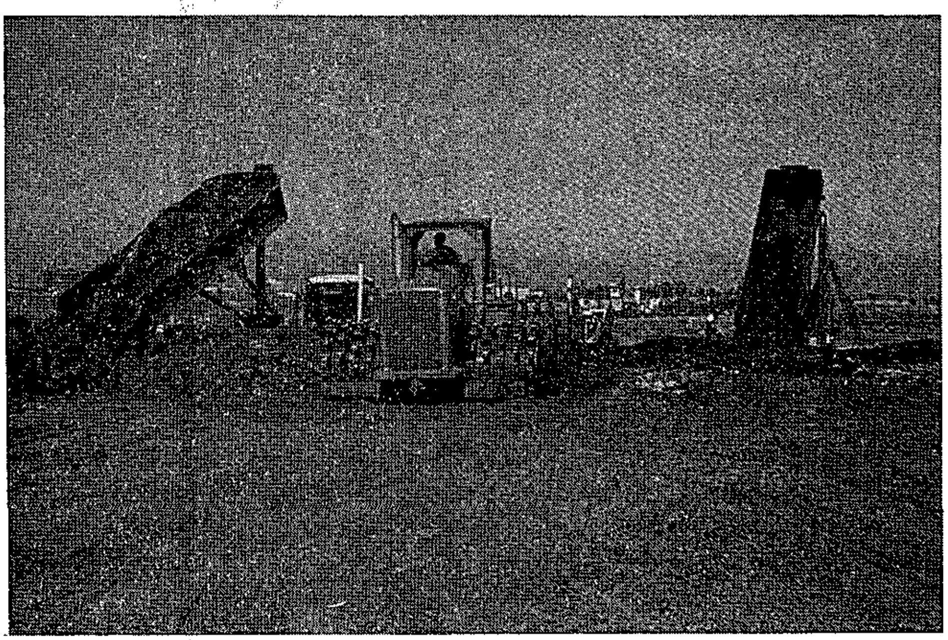

Figure 12 Rear dump trucks unloading refuse.

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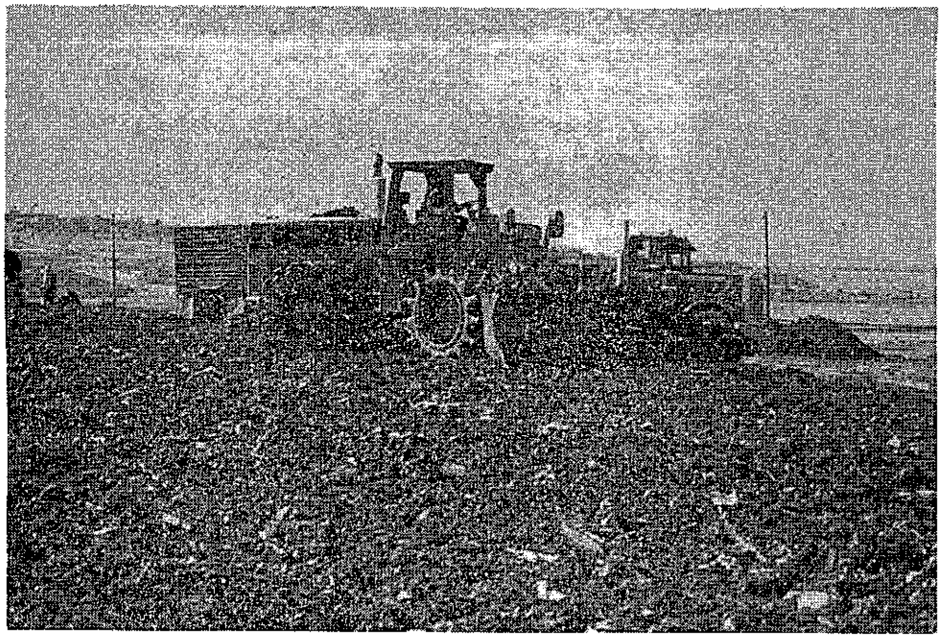

Figure 13 Sheepsfoot compactor processing refuse-soil layer.

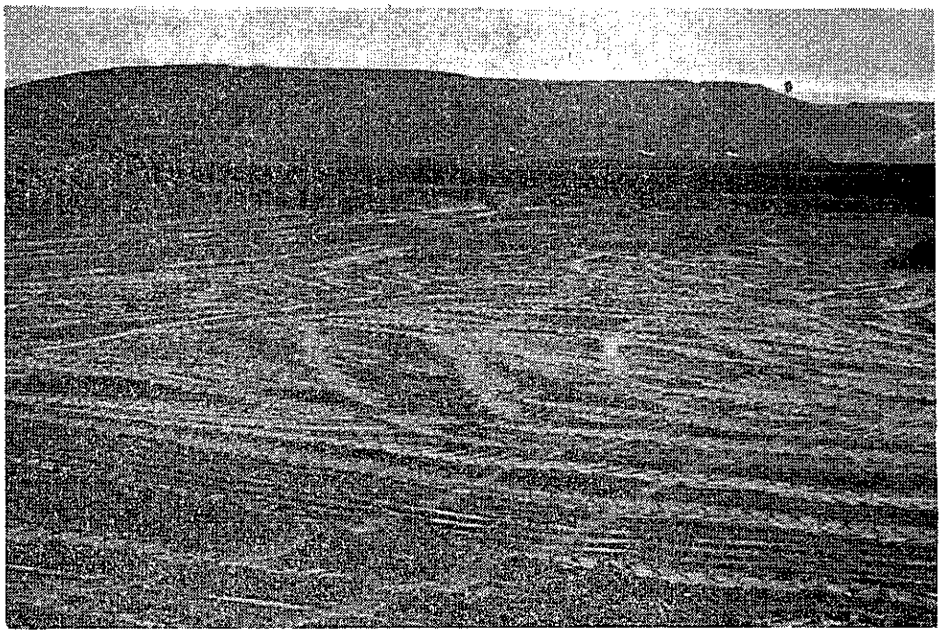

Figure 14 Embankment ready for another lift of refuse.

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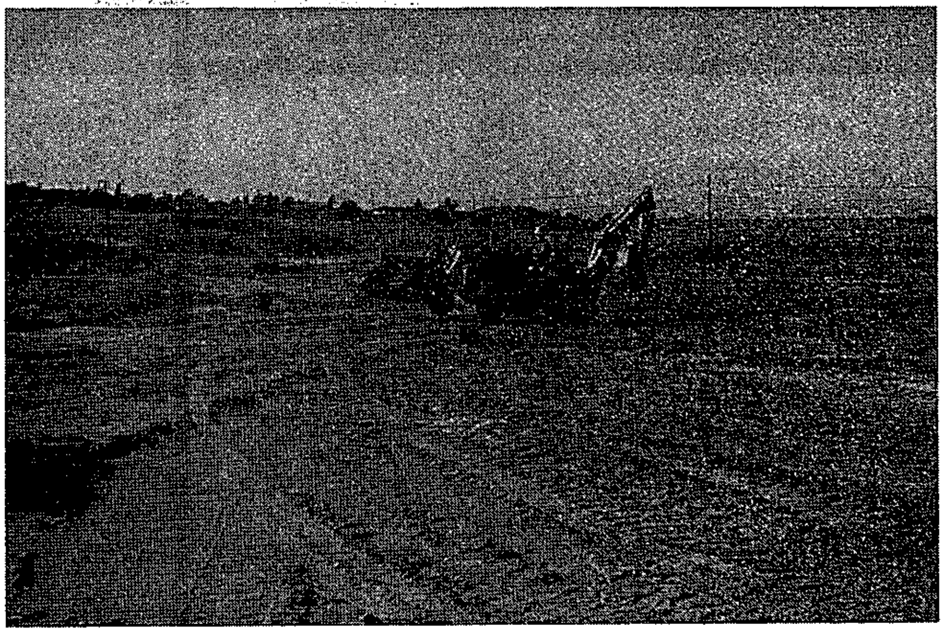

Figure 15 Backhoe removing unsuitable material.

Figure 16 Bottom dump delivers load as rubber-tired dozer spreads soil over refuse.

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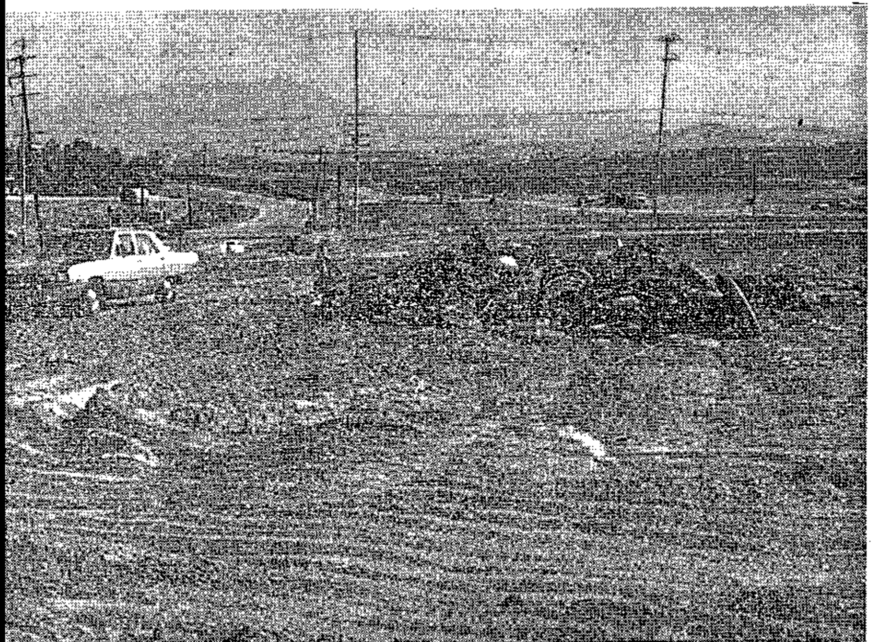

ure 17 Unsuitable refuse stockpiled for removal to active dump.

ure 18 Refuse rejected as unsuitable.

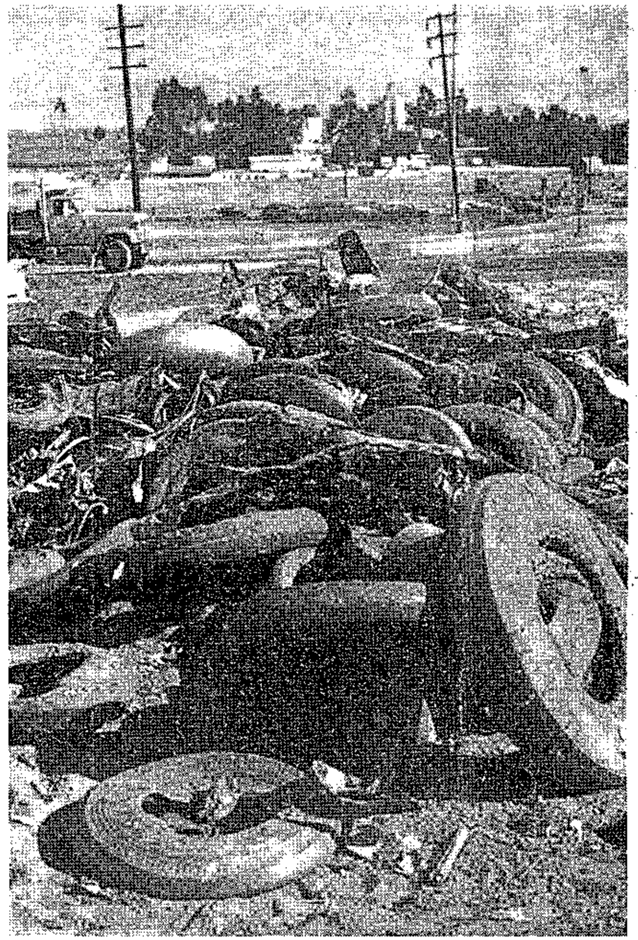

Figure 19 Refuse rejected as unsuitable.

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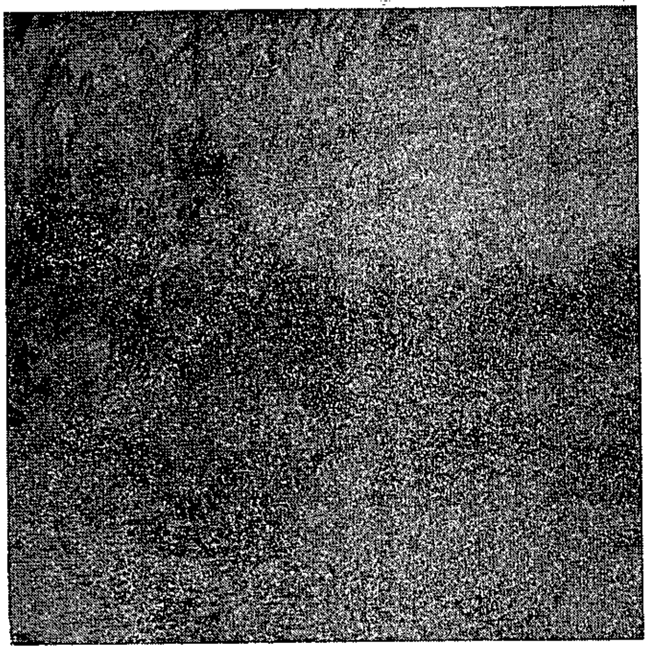

Figure 20 Blended refuse layer (Center of Photo) exposed by 5-foot deep trench excavation.

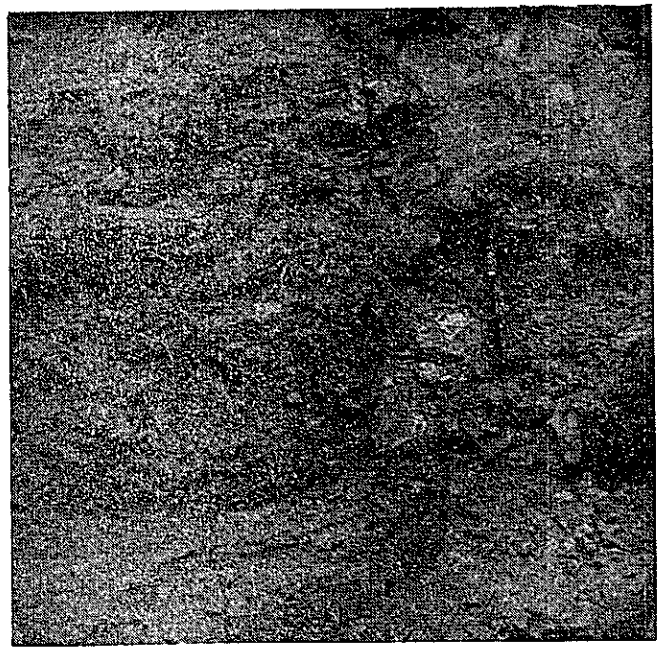

Figure 21 Close-up view of blended refuse seen in Figure 20.

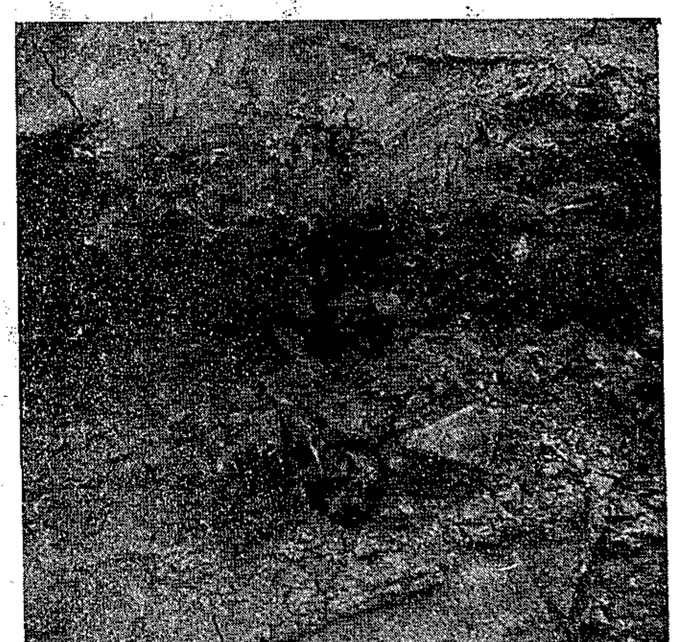

Figure 22 Close-up view of blended refuse layer.

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Figure 23 Blended refuse exposed by gully erosion on fill side slope.

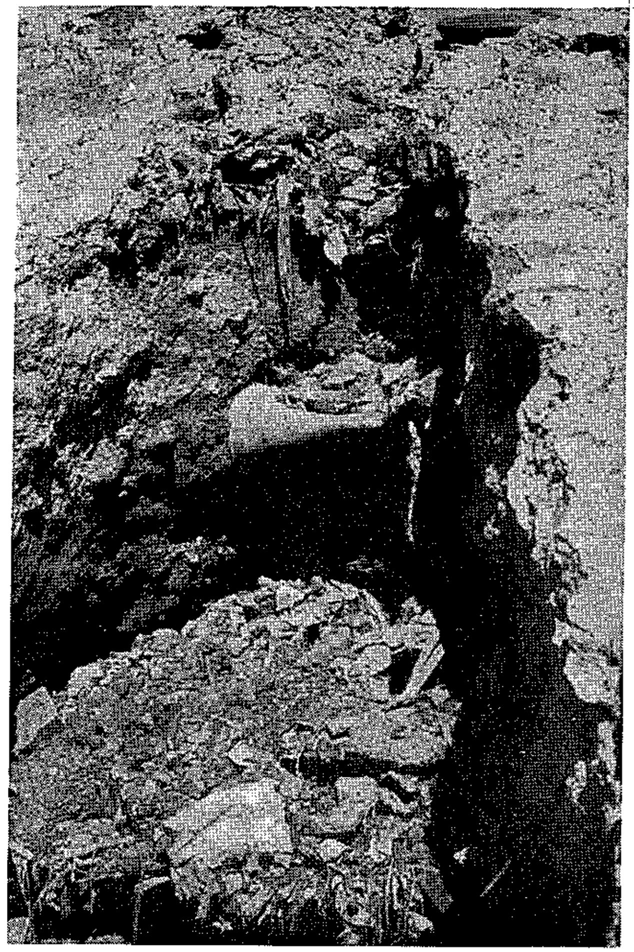

Figure 24 Close-up view of area shown in Figure 23.

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TRANSPORTATION RESEARCH RECORD 593

Use of Waste Materials and Soil Stabilization

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Use of Waste Materials in Embankment Construction

Raymond A. Forsyth and Joseph P. Egan, Jr., Division of Structures and Engineering Services, California Department of Transportation

The impact of environmental constraints and economic considerations compels the engineer to seek new and novel techniques for using waste materials in embankment construction. This paper describes the use of sanitary landfill and nonbiodegradable waste (discarded tires) and design criteria for incorporating waste material into California highway embankments. Construction guidelines and theoretical considerations are presented. One case history and plans for a test embankment that will be stabilized by tire sidewall mats are described.

The California Department of Transportation, like most other road-building organizations, has in the past placed severe restriction on the incorporation of unsuitable materials into highway embankments. Clearing and grubbing were an important and rigidly adhered to first step in the highway construction process. The burial of logs and stumps was prohibited and, indeed, in some cases, knots and twigs were picked out of embankments as part of the construction process. When sanitary landfills were crossed, the waste was normally stripped to original ground and disposed of before construction of the embankment began.

Recently, environmental restrictions, economics, and concern for visual impact have necessitated construction of highways over marginal to extremely difficult terrain. The options with respect to development of borrow and waste disposal sites have been severely restricted and have thus compounded the problem. Thus, reevaluation of past highway practice with respect to waste or unsuitable materials has become necessary.

This paper discusses the use of two types of waste materials incorporated into embankments constructed along California highways: sanitary landfill waste and nonbiodegradable waste (discarded tires).

Recently several case histories (1, 2), concerning the crossing of sanitary landfills with highway embankments, have appeared in the literature. They describe the construction technique and the results of measures aimed at minimizing postconstruction settlements.

Publication of this paper sponsored by Committee on Earthwork Construction.

On Calif-73 in Orange County, California DOT is nearing completion of a project in which sanitary landfill waste is incorporated into embankment construction. This project is described as is a test embankment yet to be constructed, in which, it is believed, a systematic incorporation of tire waste will serve to benefit the fill and thus permit steeper than normal side slopes and increase resistance to seismic loading.

SANITARY LANDFILL WASTE

General Design Criteria

No general design criteria are described because the contract specifications are described in the discussion of the case history.

Case History

The sanitary landfill waste project consists primarily of an interchange in Newport Beach, California, near the Irvine campus of the University of California (Figure 1). One segment of the interchange provides ramp access to MacArthur Boulevard, which was relocated to accommodate future full alignment.

The results of a foundation investigation revealed that foundation soils were generally soft and compressible, and this necessitated 2:1 side slopes, stabilizing berms, waiting periods, and controlled rates of loading for embankment construction.

The general pattern of foundation soils consists of alternating strata of compressible clay and fine to coarse sands that appear to be free draining. Figure 2 shows the boring locations and the log of the borings for a portion of the realigned MacArthur Boulevard, including a portion of the sanitary landfill.

As indicated by the borings, a sanitary landfill containing 152 910 m^3 (200 000 yd^3) of refuse occupied a section of the line along which the realigned MacArthur Boulevard and University Drive would be constructed. Construction of this landfill began in 1954 and was completed with 0.6 m (2 ft) of earth cover in 1961.

As the design of the interchange was nearing completion, it became apparent that removal of this huge

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quantity of waste would involve a tremendous expenditure. Construction of embankments over the landfill would subject the roadway to intolerable long-term settlement and compound the problem already present because of the nature of the subgrade soils.

Inquiries by designers with respect to disposal of the waste revealed that the only available option was placement in another sanitary landfill. Since the project was deficient in embankment, the 152 910 m^3 (200 000 yd^3) would have to be replaced by material obtained from outside the project limits and delivered to the site at an estimated cost of \$3.92/m^3 (\$3.00/yd^3). Thus, the potential net savings available by using the waste in embankment construction was estimated at \$900 000. This finding prompted further study of the possibility of using the waste in the embankments. There was little information to draw on, except for recent limited experience in the burial of wood waste in embankments. The specifications ultimately developed by the District Design, Construction, and Transportation Laboratory personnel for this purpose are as follows:

> Those areas shown on the plans as "Refuse Removal Area" are areas of unsuitable material. The Contractor shall excavate the refuse cover and refuse material and construct embankments within the excavated refuse area with material obtained from excavation within the project limits (except excavated refuse material) or borrow.
>
> At the option of the Contractor, excavated refuse material may be used in embankment construction in the areas shown on the plans as "Refuse Embankment Areas."
>
> In addition to the requirements in Section 19-5, "Compaction," and Section 19-6, "Embankment Construction," of the Standard Specifications, the placement of excavated refuse material in embankments shall conform to the following:
>
> 1. Excavated refuse material shall be thoroughly mixed with suitable embankment material at a rate not to exceed 50 percent of the mixture.
> 2. Each layer of the refuse material mixture shall be covered with at least two layers of suitable embankment material.
> 3. No layer of the refuse material mixture shall be placed within four feet of finished grade.
> 4. Rock, portland cement concrete, asphalt concrete, ferrous and nonferrous metals shall not exceed one foot in the vertical dimension when placed in embankments.
> 5. All other material including biodegradable material shall not exceed one-half foot in greatest dimension.

A typical embankment cross section is shown in Figure 3.

The heterogeneous nature of the waste precluded compaction control by conventional means. However, it was reasoned that placement of waste in relatively thin lifts sandwiched between layers of soil would minimize the risk of low densification, since a relatively firm working table would be necessary to achieve the specification compaction requirement in the soils layers.

Refuse embankment construction requirements of the special provisions to the contract include stripping surface materials at refuse embankment sites to an elevation of 1.2 m (4 ft) and constructing embankments to a finished embankment height subject to the following rates of loading:

1. Place 2.7 m (9 ft) of embankment at a rate of 0.41 m (1.33 ft) per week followed by a 60-day waiting period;
2. Construct the embankment to an elevation of 6.7 m (22 ft) at a rate not to exceed 0.41 m (1.33 ft) per week followed by a 60-day waiting period; and
3. From 5.5 m (18 ft) to finished grade elevation, construct at a uniform rate not to exceed 0.9 m (3 ft) per week.

Heave stakes, piezometers, settlement platforms, benchmarks, and inclinometers were installed for construction control. Additional benchmarks were installed at the top of the fills above the settlement platforms at original ground to monitor compression occurring within the fill itself.

Excavation of the landfill exposed a composition of wood, stumps, paper, fibrous wastes, cans, bedsprings, pipe, wire, glass containers, plastics, tires, bricks, and concrete debris. Organic materials encountered were generally in a good state of preservation. Newspapers, dated in the late 1950s, were clear and readable. As had been anticipated, based on the exploration of the fill in late 1970, groundwater was encountered from 4.6 to 6.1 m (15 to 20 ft) below ground surface and was ponded and later pumped into tank trucks for use in the compaction operation. No discharge of groundwater was permitted to enter into San Diego Creek. Leachate was not considered to be a problem, and no program to monitor leachates from the embankment was initiated since the refuse was to be incorporated into embankments several meters above the water table and sandwiched between layers of relatively impermeable soil. The refuse was excavated from the locations shown in Figure 1 and hauled to the embankment with rear-dump trailer and tractor trucks.

The device that ultimately proved most successful for refuse excavation and loading was a hydraulic backhoe. This had several advantages, including a digging action from the top downward into the saturated refuse that penetrated the rags and paper on the initial thrust and filled the bucket. Wet soft areas were worked by reaching out and down; the machine carriage did not enter the area and bog down. The backhoe capacity was found to be approximately 229 m^3 (300 yd^3) of refuse per hour. After the refuse was hauled to the embankment location and dumped, bulldozers spread the material in 15.2-cm-thick (6-in) lifts as shown in Figure 4. At this point, unsuitable pieces including tires (Figure 5) were picked out, stockpiled, and eventually hauled away for disposal at a public dump.

Embankment soils for blending with the refuse were hauled to the site in twin-bottom dump trailers. The soil was spread over the in-place refuse with rubber-tired bulldozers and a motor grader as shown in Figure 6. Mixing was accomplished with either a sheepsfoot roller pulled by bulldozers or a self-propelled sheepsfoot compactor as shown in Figure 4. The compactor spikes penetrated the soil and rubbish and pulled, ripped, and split the rubbish as it was mixed with the soil and compacted. The principal problem was the tendency of the compactor to become plugged with refuse. The sandy soil that was used for the embankment proved to be an asset for the blending operation because of its low cohesion. A similar attempt to mix cohesive or clayey soils with the refuse would have been extremely difficult, if not impossible.

The moisture content of the refuse buried was from dry to saturated. Saturated refuse was spread and allowed to air dry before it was blended with the soil. Specifications were included for odor control of the refuse during handling operations. A commercial deodorant, available for use if obnoxious odors were encountered on this project, was not necessary.

Compaction control of the soil lifts sandwiched between the blended refuse lifts was maintained with nuclear gauges. A relative compaction requirement of 90 percent, according to California Test Method 216, was specified and achieved for the soil portion of the embankment. Compaction control of the blended refuse layers was achieved by visual inspection. Inspectors observed the blending and compaction of the refuse layers and directed the modification of the operation where inadequate compaction or mixing was observed. Exposed

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Figure 1. Sanitary landfill waste project location map.

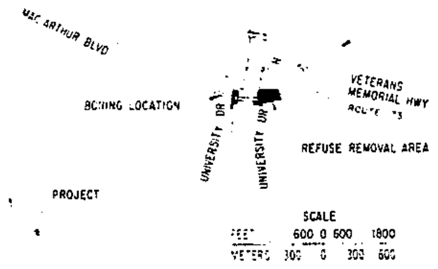


Figure 2. Boring locations and soil profile along portion of realigned MacArthur Boulevard.

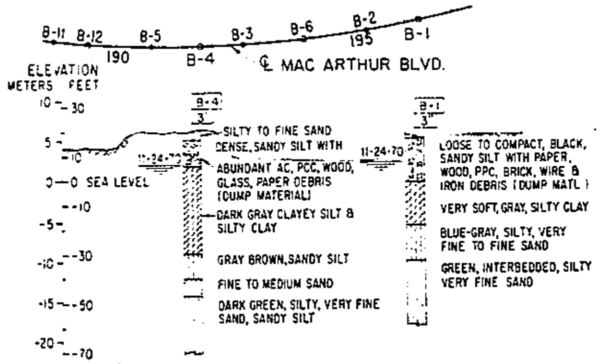


Figure 4. Sheepsfoot compactor processing refuse-soil layer.

Figure 3. Cross section of engineered refuse fill and substrata.

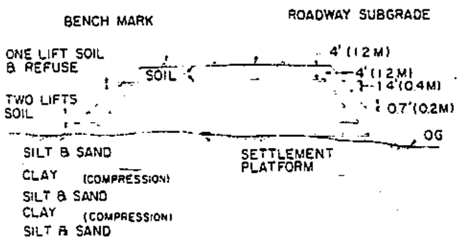
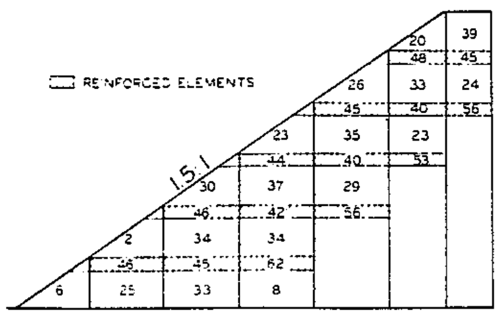


Figure 5. Refuse rejected as unsuitable.

Figure 6. Bottom dump delivering load as rubber-tired bulldozer spreads soil over refuse.

Figure 7. Blended refuse layer exposed by 1.5-m-deep trench excavation.

Figure 8. Percentage reduction of maximum dynamic shear stress determined by finite element mesh.



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layers of the blended refuse were seen as a result of an excavation for a drainage culvert as shown in Figure 7. The blended refuse layers appear across the center of Figure 7, sandwiched between two soil layers. No cavities were observed in the exposed layer. The soil and refuse were moist and thoroughly mixed and could be separated only by using a handpick. The layer appeared to be well compacted.

The sandy soil used for embankment eased the problem of mixing considerably; the success of such an operation with cohesive materials is doubtful. As of June 1976, no significant amount of compression has been detected within the soil-waste fills.

NONBIODEGRADABLE WASTE

General Design Criteria

Engineers have long been aware of the stabilizing effects of inclusions of various materials in earthworks. The first disciplined, and by far the most extensive and successful, application of soil reinforcement was developed by Vidal (3) in the late 1950s. Vidal's system of reinforced earth consists of placing steel reinforcing strips at predetermined intervals within the fill mass for the purpose of providing tensile or cohesive strength in a relatively cohesionless material. For a soil to be satisfactory for reinforced earth construction, Vidal suggests that it be granular and have an angle of internal friction of at least 25 deg so that adequate friction resistance can be developed between the soil and the reinforcing material.

The stabilizing effect of materials with relatively high tensile strength in soil has been observed since ancient times. Increased shear strength with certain types of nonbiodegradable materials was noted during a laboratory study by California DOT (4).

One of the most perplexing solid waste disposal problems involves automobile tires. It has been estimated that approximately 200 million tires are discarded each year in the United States. Air quality legislation precludes burning as a solution. A major problem with respect to burial of tire carcasses in soil is their tendency to eventually work up to the surface. The problem of tire disposal was of sufficient magnitude in California to prompt passage of House Resolution 37 in the 1973 California legislative session, which charged the California DOT to study the problem of abandoned tires and develop possible solutions for their disposal or recycling.

Investigation of the problem of tire disposal revealed that equipment is now commercially available to economically separate tire sidewalls and treads, the latter having been found to be a commercially valuable commodity. The sidewalls alone, having a nearly flat configuration and extremely high tensile strength, are an obvious possibility for soil reinforcement and, if they are placed in strips or mats, could serve to greatly increase the internal stability of an embankment, based on the reinforced earth principle. To go one step further, it was speculated that embankments stabilized in this manner could be constructed at much steeper side slopes than would otherwise be possible and could provide a means of disposal of this troublesome waste product.

To study this possibility further, California DOT Transportation Laboratory conducted an analysis to determine the theoretical effects of tire reinforcement on earthquake resistance of embankments. This analysis assumed tire placement in mats extending for widths of 0.8 of the embankment height at vertical intervals of 1.2 m (4 ft). It was accomplished with the Quad-4 finite element program developed at the University of California, Berkeley. The finite element mesh (Figure 8) consisted of elements representing the reinforcing mat and boundary soil.

The embankment was assumed to have a relative density of 90 percent and a density of 2082 kg/m³ (130 lb/ft³). Shear modulus G was assumed to vary with overburden height as shown by the following equation (4):

$$G = K_2(\sigma_o')^{1/2} \qquad (1)$$

where

G = shear modulus in pascals,
K_2 = function of relative density D_r, and
σ_o' = effective overburden stress in pascals.

The foundation soil was also assumed to be sandy and had a relative density of 75 percent and a density of 2082 kg/m³ (130 lb/ft³). From equation 1, the K_2 of the 1.5 m (5 ft) of foundation soil is 61. For the composite material, a constant shear modulus of G = 6.37 MPa (133 kips/ft²) was used, based on the results of tests on rubber tire specimens. A constant damping factor of 25 percent was also used. The embankment was assumed to be 7 m (23 ft) in height with 1½:1 side slopes. The earthquake selected was the California Institute of Technology type C-1 with a maximum acceleration of 0.3 g, a period of 0.35 s, and a duration of 12 s applied at the base of 1.5 m (5 ft) of foundation material. This would correspond to an earthquake measuring 7 on the Richter scale at a distance of 24 km (15 miles) from the fault. The results in terms of change or reduction in the dynamic shear stress resulting from reinforcement are shown in Figure 8. Under these conditions, dynamic shear stress would be reduced in the embankment soil by 20 to 62 percent, at an average of about 33 percent. The greatest reduction occurs in the interior; this would indicate that failure, if it did occur, would probably be on the surface. Shear strain would experience a similar trend and would be reduced by about 33 percent in the embankment soil. These values would, of course, vary with side slope, type of soil, earthquake intensity and duration, and fill height. The results of this analysis and the earlier laboratory study of the stabilizing effect of waste led to a decision to construct a prototype test embankment in which tire sidewall mats were used for reinforcement. Federal Highway Administration approval for the instrumentation and analysis portions as a Highway Planning and Research (HPR) project was received on August 8, 1973.

Plans for Embankment

In early spring 1976, a test embankment was suggested by California DOT that, although not ideal from a research standpoint, would definitely be constructed during the 1976 construction season. It is located on Calif-236, about 24 km (15 miles) north of Santa Cruz (Figure 9). The proposal stated that a sidehill fill slipout would be corrected by constructing an embankment approximately 91.5 m long and 15 m high (300 ft long and 50 ft high).

The slide is located on the northwest slope of a narrow, densely forested ridge. This area is underlain by the Rices mudstone member of the San Lorenzo formation, Oligocene Age, and consists of poorly cemented mudstones, siltstone, and sandstone. Bedding planes dip steeply northeastward parallel to the ridge. An investigation of the slide mechanism revealed a depth of unconsolidated and loose slide material and freewater from 18.3 to 21.3 m (60 to 70 ft) below roadway elevation. It was concluded that the primary cause of the slide

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was subsurface water that, over a period of years, had saturated and weakened the earth mass supporting the roadway and ultimately had caused failure. The generally unfavorably bedded fractured planes were also a factor.

The experimental embankment is to be constructed on a side slope of ½:1. It is estimated that the steepened slope, made possible by stabilization, will save approximately 68 810 m^3 (90 000 yd^3) of embankment that would have been necessary with the conventional 1½:1 side slope because of the sloping nature of the terrain.

The essential elements of the test embankment include removal of the slide debris to well below the apparent slide plane, construction of a positive subsurface drainage system to relieve the cause of initial failure, and extensive instrumentation of the central section to monitor fill behavior (Figure 10). The outer 1.8 m (6 ft) of the embankment will be treated with straw. Seed and mulch will be air blown onto the face of the slope when construction is completed.

The tire sidewall mats will extend 10.2 to 15.2 cm (4 to 6 in) beyond the edge of the embankment to minimize erosion until permanent growth is established. The resulting artificial serrations should serve as energy dissipators for surface runoff. Mat embedment depth will be sufficient so that the reinforced portion of the embankment, if considered as a gravity system, will have sufficient mass to resist overturning and sliding.

In all large direct shear tests of the tire sidewall mats embedded in soil, the critical element was the connector rather than slippage between soil and tire mat or tensile failure of the tire sidewall. Initial consideration was given to the use of heavy (14-gauge), pneumatically fired staples. The results of pull tests using up to four such staples revealed an inconsistent performance, due primarily to the difficulty in obtaining consistently tight staple closure on the bottom side of the mat.

The clip type of connector that ultimately evolved is shown in Figure 11. Pull tests conducted on this type of connector, using 6.4, 7.9, and 9.5-mm-diameter (¼, ⁵⁄₁₆, and ⅜-in) cold rolled steel, revealed that the 9.5-mm-diameter (⅜-in) clip provided adequate tensile strength; this was true even when the estimated corrosion loss during the design life of the embankment was considered. Figure 12 shows the peak connector tensile strength versus strength required for embankment heights up to 18.3 m (60 ft) for the range of embankment soil shear strength properties anticipated on the project. The results of two actual laboratory tests are superimposed.

In addition to ease of installation, another important advantage of the clip connection is increased rigidity of the mat since the clips will grip the tire sidewall bead.

In April 1976, FHWA was requested to provide demonstration project funds to cover the costs of tire sidewalls, clips, and placement. This request was subsequently approved. Instrumentation analysis of data will be accomplished under the aforementioned ongoing HPR project. Project construction is expected to begin between August 15 and September 1, 1976, and to be completed within 1 month to 6 weeks. Instruments will be monitored for 2 years after construction.

SUMMARY AND CONCLUSIONS

Environmental constraints and economic considerations recently have necessitated a reevaluation of past highway practice with respect to inclusion of waste materials in embankments.

Experience with the Calif-73 project in Orange County thus far has demonstrated that satisfactory embankments can be constructed by using landfill waste. Whether landfill waste should be used must depend on an evaluation of engineering feasibility and aesthetics, based on availability of disposal sites, volume of landfill wastes, waste composition, state of waste decomposition, possible deleterious effect of the use of landfill waste on water quality, nature of embankment soil, and time constraints (effect of waiting periods).

A primary concern is the heterogeneous nature of the material. For obvious reasons, relative compaction cannot be used as a control test. Thus, the engineer must judge and supervise the operation and be prepared to make modifications to the character of the waste. Shear strength and consolidation characteristics, if necessary, must be determined by in situ testing. Instrumentation is of fundamental importance in controlling or modifying the operation.

Laboratory studies and dynamic response analysis have indicated that the systematic inclusion of certain nonbiodegradable wastes (tire sidewalls) could possibly benefit a fill and thus permit steeper side slopes and increase resistance to earthquake loading.

A test embankment to evaluate this premise is now planned for construction on Calif-236 in Santa Cruz County in early autumn 1976. It will be constructed at a ½:1 side slope reinforced with tire sidewall mats at 0.6-m (2-ft) intervals. The performance of the completed embankment will be monitored by instrumentation installed during its construction.

ACKNOWLEDGMENTS

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The contents of this report reflect the views of the Transportation Laboratory, which is responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the state of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Figure 9. Nonbiodegradable waste project location map.

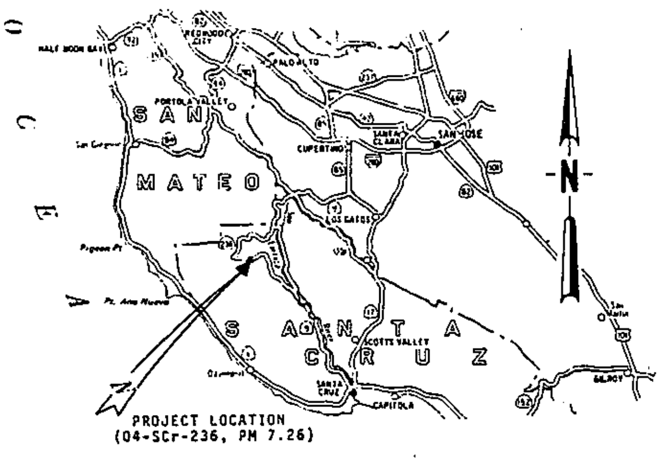


Figure 12. Theoretical peak connector strength versus required strength of 9.5-mm steel bar in cohesive and cohesionless soils for embankment heights to 18 m.

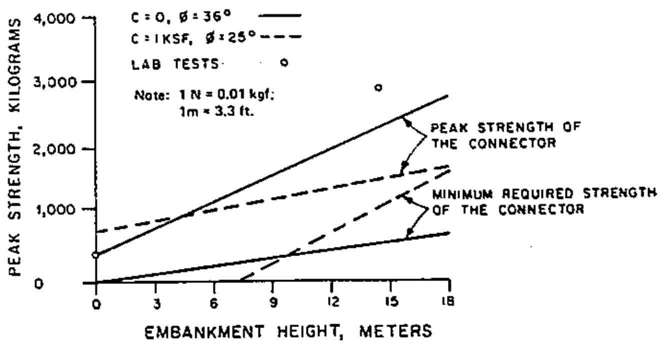


Figure 10. Cross section of tire reinforcement and instrumentation.

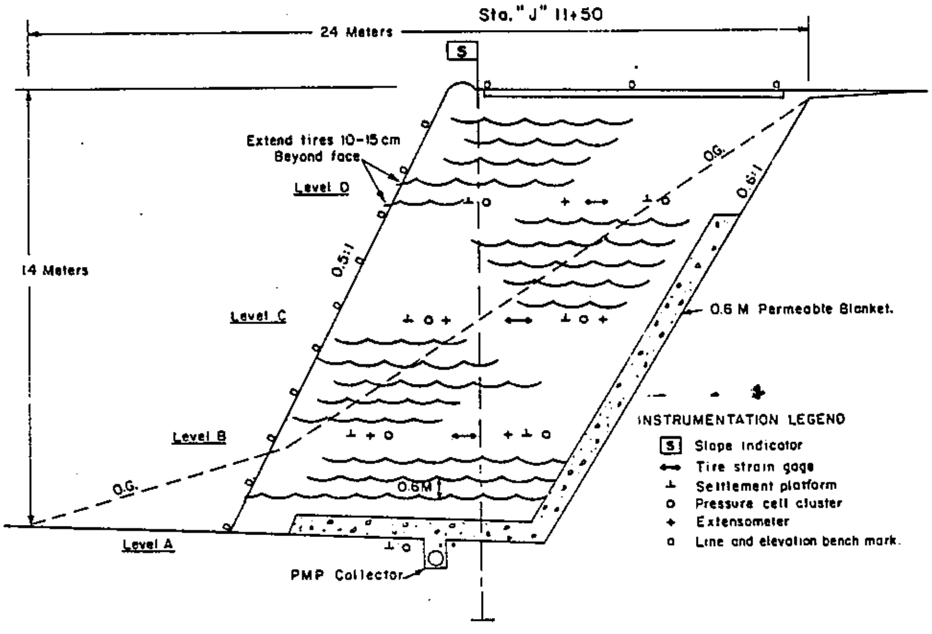
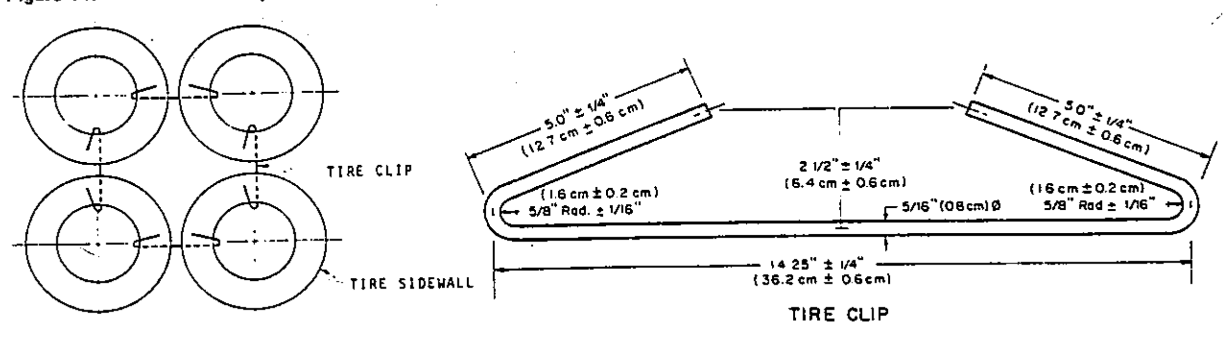


Figure 11. Plan view of tire placement and tie arrangement.



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